Precision Agriculture, 1, 291–300 (1999)

Relationship Between Spectral Data from an Aerial Image and Soil Organic Matter and Phosphorus Levels

GARY E. VARVEL,* MICHAEL R. SCHLEMMER, AND JAMES S. SCHEPERS
USDA-ARS and Dep. of Agronomy, Univ. of Nebraska, Lincoln, NE 68583

Abstract. Early ventures into site-specific management involved fertilizer management decisions based on soil chemical properties characterized by some form of grid sampling. This is both labor and capital intensive and practitioners quickly began investigating other methods to get a measure of spatial variability. Aerial photographs, which were mainly used to evaluate and assess crop status, allow for the collection of whole-field data at relatively low cost. Our objective is to determine what relationships exist between aerial spectral data and intensive grid soil test results and whether this information can be used to improve future soil sampling strategies. Soil-test organic matter (OM) and Bray-1 P concentrations were measured on soil samples taken using an alternating 12.2- by 24.4-m grid in late March 1994 from a quarter section under center pivot irrigation. Spectral data were collected in the spring of 1996 prior to planting using a multispectral network of digital cameras. Correlations of brightness values from the blue, green, and NIR bands with both OM and Bray-1 P were significant, but relatively low. Normality tests revealed that brightness values for the spectral data sets were generally evenly distributed while those of the soil test OM and Bray-1 P were positively skewed. Many of the very high soil-test data values were due to past management. When those values were removed from the database, greater correlations between spectral data and soil test data were obtained. These results substantiated that aerial imagery can be used to improve sampling strategies, but it must be used in conjunction with existing knowledge and past management histories.

Keywords: Grid sampling, soil test, brightness values, skewness, kurtosis

Introduction

Early approaches to site-specific management involved some form of grid soil sampling to characterize soil chemical properties. Collection and analysis costs make this approach impractical on a large scale. Furthermore, variable-rate application of nutrients based on grid soil sampling results often fails to correct spatial variability in crop growth and yield. This situation has prompted interest in other methodologies to characterize spatial variability.

One alternative was to use information in published soil surveys of soil types as the basis for sampling strategies. This procedure tends to group similar soils based on soil classification data and has met with varying degrees of success. Varvel et al. (1981) indicated significant improvement in soil test P results and improved P fertilizer recommendations when soils were sampled by soil series based on soil

Joint contribution of USDA-ARS and the Nebr. Agric. Res. Div., Journal Series No. 12213.
* Corresponding author.

survey maps. In contrast, Ferguson et al. (1996) indicated sampling according to soil survey data alone was not adequate to design a sampling strategy based on their experience from an intensively sampled site. However, they indicated that future soil survey maps could become more useful for site-specific management if more detail were added. In both cases, it was suggested that any sampling procedure should use all available data.

A novel approach involves using aerial photographs throughout the year to evaluate both soil and crop conditions and relationships. Aerial images provide information from large areas at fairly low cost, but past attempts to find agricultural applications have met with varying degrees of success. Wilcox et al. (1994) used satellite images of bare soil to gain information on organic matter content. They related this to past management, erosion, water retention, and nutrient status. Pocknee et al. (1996) used an aerial image to direct sampling strategies for soil P and pH in the coastal plain area. These strategies provide some indication that soil color may indeed be related to soil organic matter and P levels, which, with respect to organic matter is understandable. However, this relationship with P levels is not as clear, but may be simply related to the fact that soils with higher organic matter levels may also have higher P levels. This relationship does not always exist, but it may be present in enough situations to justify it use in specific situations.

Our objective was to determine if relationships exist between spectral data in an aerial image and soil test results from an intensive grid soil sampling and whether these relationships can be used to improve future soil sampling strategies.

Methods and materials

A quarter-section under center-pivot irrigated corn production near Shelton, Nebraska was used for this study. Cropping history information indicated the field had been planted to corn from 1978 to 1992 using conventional tillage. A ridge-till production system has been used since 1993, which results in accumulation of partially buried residue in the interrow area after planting. Two soil types, Hord (fine-silty, mixed, mesic Pachic Haplustolls) and Blendon (coarse-loamy, mixed, superactive, mesic Pachic Haplustolls), represent the majority of the field. The topography is slightly rolling and the maximum difference in elevation across the field is approximately 2 m.

Soil samples to a depth of 20 cm were collected in late March 1994 at the beginning of the study on a 12.2 by 24.4 m alternate grid, which resulted in approximately 2200 grid points. These samples consisted of a single ~5-cm diameter core taken on the ridge shoulder (midway between the furrow and ridge) at each grid point. Soil samples from every grid point were analyzed for both organic matter and Bray-1 P concentrations (Missouri Agric. Exp. Sta., 1998). Soil test results were then surface mapped using an inverse distance weighting function and categorized for the entire quarter-section using the ERDAS Imagine (ERDAS Inc., Atlanta, GA) software package. Organic matter and soil-test Bray-1 P concentrations were grouped into eight categories from the surface map.

A composite aerial image of bare soil was taken in the spring of 1996 prior to planting to generate a multi-spectral data base. A network of four Kodak™ [1] Megaplus 1.4I digital cameras were used with appropriate filters to construct the multispectral data base of blue, green, red, and near-infrared brightness. These data were collected from a height of 1000 m and resulted in a resolution of approximately 1 m^2 per pixel. A problem with the digital camera setup to record data from the red band prevented it from being collected. However, the cameras recorded brightness values for each pixel in the blue (450–520 nm), green (520–600 nm), and NIR (775–900 nm) bands. Brightness values, which can vary from date to date due to sun angle, sensor gain, atmospheric conditions, etc., were used instead of reflectance because there was no calibration standard in the image area. However, in spite of these potential problems, the differences in brightness values are still relative and can be used for comparisons such as these.

These values were then correlated with OM and Bray-1 P concentrations using PROC Univariate (SAS, 1992). Means, standard deviations, minimum and maximum values, and tests of normality were also determined using PROC Univariate.

Results and discussion

A bare soil aerial photograph was taken in 1994 using conventional film, which was scanned and digitized, but the data were of very low quality. No bare soil photographs were taken in 1995. Given these problems, it was deemed most appropriate to use the 1996 bare soil image, since both soil organic matter and P levels do not change dramatically with time.

The composite digital image of bare soil taken before the 1996 growing season shows spatial variability in soil color (Figure 1). Figures 2 and 3 present surface maps of the OM and Bray-1 P concentrations, respectively, from the intensive alternate grid soil sampling scheme. Using the Imagine software, soil test concentrations were mapped using gray scales to represent category concentrations for OM and Bray-1 P. Visual examination and comparison of these figures indicate similar patterns between the bare soil image and the surface maps of OM and Bray-1 P. Similarities were also observed between surface maps of OM and Bray-1 P (Figures 2 and 3), which should not be surprising since soil organic matter and Bray-1 P levels were significantly correlated ($r = 0.57$). Most of the dark areas on the composite aerial image (Figure 1) correspond well with areas on the surface maps of OM (Figure 2) and Bray-1 P (Figure 3) of highest soil-test values. Lighter areas on the composite aerial image likewise tend to be lightest (lower values) on the soil-test surface maps.

These similarities prompted us to make further comparisons to determine if these patterns and relationships were statistically significant and predictable. Since the digital camera system had recorded brightness values for each pixel in the bare soil image, values from the single pixel located at the same georeferenced spot as where the soil samples were taken were then correlated with soil test results from that spot. Summary data used for these comparisons are shown in Table 1.

Figure 1. Bare soil composite digital image of irrigated quarter section near Shelton, Nebraska taken in the spring of 1996 before planting.

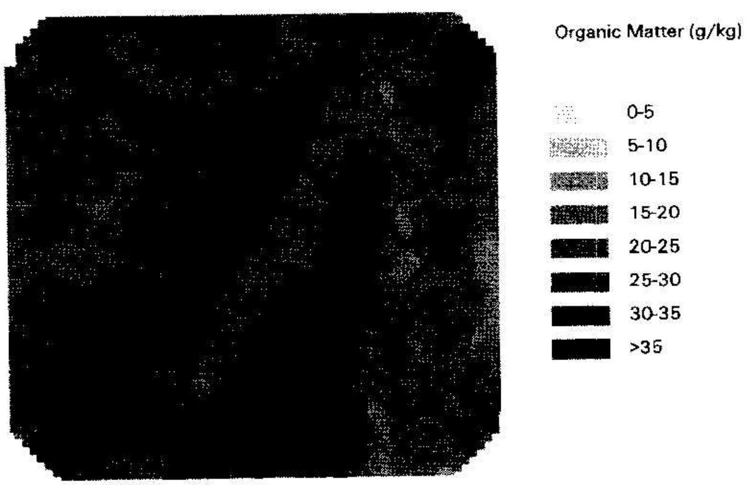

Figure 2. Surface map of soil OM concentrations from an intensive grid soil sampling of irrigated quarter section near Shelton, Nebraska generated using ERDAS Imagine software.

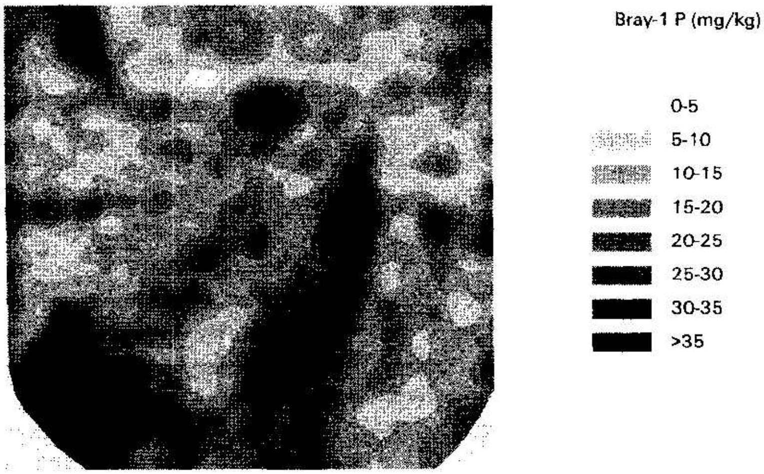

Figure 3. Surface map of soil Bray-1 P concentrations from an intensive grid soil sampling of irrigated quarter section near Shelton, Nebraska generated using ERDAS Imagine software.

Table 1. Simple statistics for soil test OM and Bray-1 P values and blue, green, and NIR band brightness values at the same georeferenced point of a quarter section near Shelton, Nebraska

	Simple statistics				
Variables	N	Mean	S.D.	Minimum	Maximum
	Whole field				
OM (g kg^{-1})	1929	22.2	4.7	9.7	46.7
Bray-1 P (mg kg^{-1})	1929	16.3	26.5	0.1	387.0
Blue†	1929	82.0	3.8	66	91
Green	1929	109.2	6.8	79	124
NIR	1929	63.0	3.3	48	72
	West half				
OM (g kg^{-1})	980	23.0	4.4	11.2	46.7
Bray-1 P (mg kg^{-1})	980	20.6	34.5	0.5	387.0
Blue	980	82.6	3.6	68	91
Green	980	111.3	6.3	86	124
NIR	980	63.9	3.1	50	72
	East half				
OM (g kg^{-1})	944	21.4	5.2	9.7	41.0
Bray-1 P (mg kg^{-1})	944	11.8	11.3	0.1	125.0
Blue	944	80.9	3.6	66	90
Green	944	106.7	6.5	79	121
NIR	944	61.6	3.2	48	68

†—Blue, Green, and NIR brightness values are unitless.

Correlations of brightness values from the blue, green, and NIR bands with both OM and Bray-1 P were significant ($p = 0.01$), but relatively low (Table 2). Correlations were greater between OM levels than Bray-1 P levels for all three bands, as expected given the effect of OM on soil color. These correlations, although statistically significant, were still considered low and prompted us to investigate additional possibilities. One thought was to include data from pixels surrounding the sampling point. The convolution function in the Imagine software is a procedure that utilizes a floating window to calculate an average of the neighboring pixels within that window. We used this procedure with a 3×3 window and then ran the correlation of these brightness values with OM and Bray-1 P levels at those points. This approach tended to improve correlations very slightly, but not to any great extent.

It became apparent that OM and Bray-1 P concentrations and brightness values were potentially from data sets with different types of distributions. Histograms and frequency distributions were used to examine the data distributions (Figure 4). Obvious differences in these visual representations (brightness values in all bands appeared to be normally distributed, while soil OM and P appeared to be log normally distributed) led us to examine the values contained in each data set.

The data sets were tested for normality using the procedure described by Snedecor and Cochran (1967). These tests included calculation of the skewness and kurtosis for each of the data sets. The skewness value for a normally distributed population is near zero, while populations with positive skewness values are skewed to the right of the mean and those with negative skewness values are skewed to the left. Snedecor and Cochran (1967) reported a kurtosis value of 3 for a normal distribution. If the value exceeds 3, there is usually an abundance of numbers in the data set near the mean and also far from it, while values less than 3 result from curves that have a shorter, broader peak around the mean.

Table 2. Correlations of brightness values for the blue, green, and NIR bands of the spectrum from a bare soil image with soil test values for OM and Bray-1 P from an intensive grid sampling of a quarter section located near Shelton, Nebraska

	Correlations (Pearson)		
Color band	WF†	W$\frac{1}{2}$	E$\frac{1}{2}$
	Organic Matter		
Blue	−0.50**	−0.48**	−0.61**
Green	−0.47**	−0.51**	−0.62**
NIR	−0.53**	−0.56**	−0.67**
	Bray-1 P		
Blue	−0.40**	−0.49**	−0.53**
Green	−0.35**	−0.46**	−0.55**
NIR	−0.36**	−0.45**	−0.60**

†—WF (whole field), W$\frac{1}{2}$ (west half of field), E$\frac{1}{2}$ (east half of field)
**—Significant at the $p = 0.01$ level

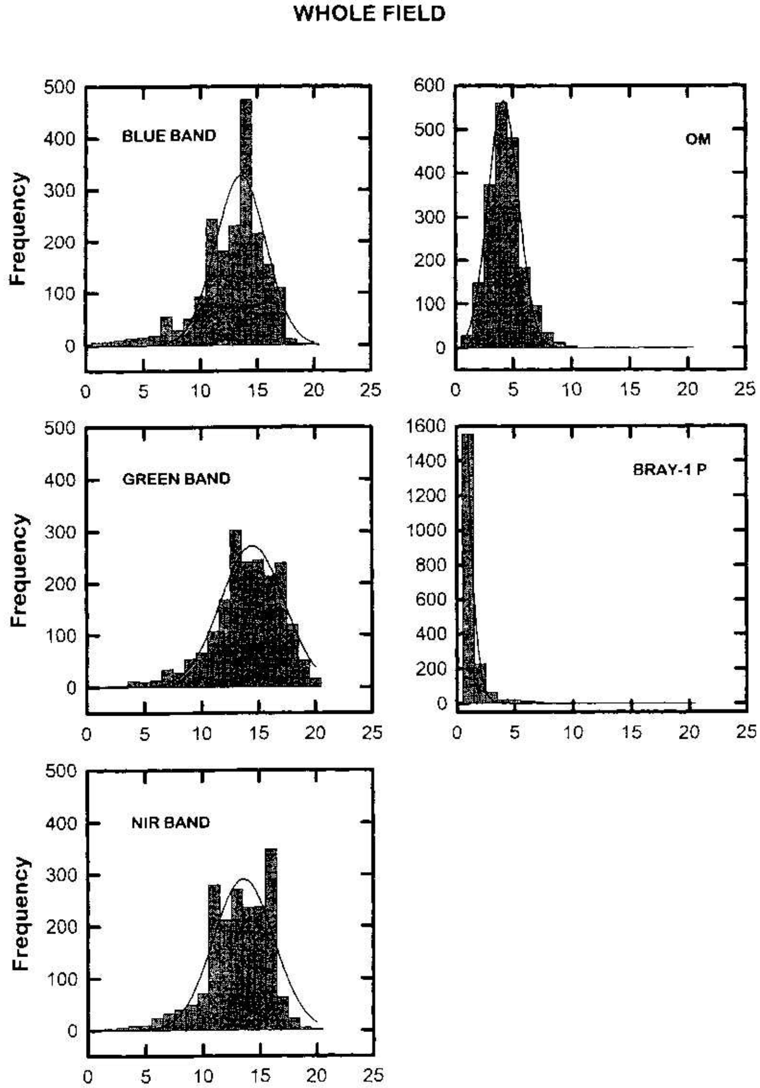

Figure 4. Frequency distributions of digital spectral data for each pixel located at each grid soil sample location and soil test OM and Bray-1 P data at those same points for irrigated quarter section near Shelton, Nebraska. All data was sorted and graphed using 20 categories to facilitate comparisons.

All tests of normality for the data sets containing brightness values indicated those values were fairly normally distributed (Table 3). Skewness and kurtosis values for all three color bands indicated a slight tail of the distribution curve on the low side of the mean and the majority of values clustered about the mean. In contrast, soil OM values were slightly skewed on the high side of the mean, but were also clustered strongly about the mean (Table 3). Soil test Bray-1 P values were strongly skewed on the high side of the mean and kurtosis values indicated a predominance of values about the mean, but also indicated several values much greater than the mean (Table 3).

Inspection of these variables and their distributions provides some indication of why simple correlations shown in Table 2 are not greater and illustrated the different types of data distributions that can be obtained in field situations. It is to be expected that the distributions of brightness values for the various color bands from the bare soil would be normal. The similarities in data distribution between color band brightness values and OM values resulted in the highest correlations (Table 2), as would be expected given that soil color is greatly dependent upon soil OM level. In contrast, although a strong clustering of Bray-1 P values around the mean indicated some tendency of normality, the large skewness and kurtosis values (Table 3) were obtained because there were a large number of Bray-1 P values much greater than the mean. The cluster of Bray-1 P values about the mean and fairly good correlations with brightness values in the blue, green, and NIR color bands (Table 2) indicated some relationship between soil color and Bray-1 P levels, even for the whole field.

Scanning through the soil test Bray-1 P data we found only one value greater than 100 mg kg^{-1} on the east side of the field, while on the west side there were over 30 values greater than 100 mg kg^{-1} and several were over 300 mg kg^{-1}. Figure 5 presents the OM and Bray-1 P data distribution for the east and west sides of the field. In both the east and west sides, a fairly normal distribution was obtained for the OM data (Figure 5). The Bray-1 P soil test levels for the two sides of the field still formed a skewed distribution (Figure 5), but there were significant differences between those distributions. Comparison of the simple statistics for the two different sides of the field supports this conclusion (Table 1). The mean, range, and standard deviation for Bray-1 P soil test values are greatest on the west side (Table 1).

This separation was used because it was a simple and pragmatic way to divide the field based on differences in past management. These differences in past management were based partly upon the existence of buildings in the southwest corner of the field (visible in the composite aerial image (Figure 1)) and informa-

Table 3. Skewness and kurtosis of OM, Bray-1 P, blue, green, and NIR band brightness values about the mean from the sampling point data sets from a quarter section near Shelton, Nebraska

	Skewness			Kurtosis		
Variables	WF†	W$\frac{1}{2}$	E$\frac{1}{2}$	WF	W$\frac{1}{2}$	E$\frac{1}{2}$
OM	0.61	0.87	0.66	1.09	2.64	0.37
Bray-1 P	6.15	4.91	3.35	54.33	32.95	18.66
Blue	−1.08	−0.94	−1.22	1.74	1.34	2.03
Green	−0.79	−0.67	−1.07	1.02	0.49	1.47
NIR	−0.89	−0.77	−1.14	1.38	1.10	1.68

†—WF (whole field), W$\frac{1}{2}$ (west half of field), E$\frac{1}{2}$ (east half of field)

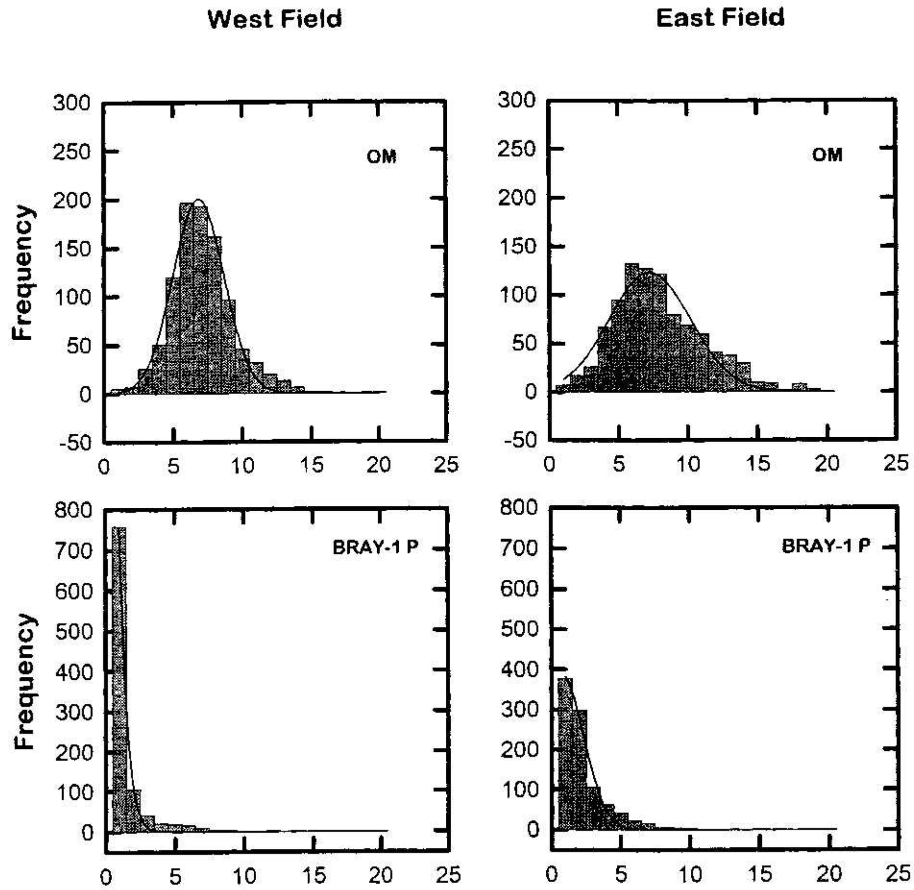

Figure 5. Frequency distributions of soil test OM and Bray-1 P data for the east and west halves of the field (separated due to past management differences). All data was sorted and graphed using 20 categories to facilitate comparisons.

tion from the current owner that this was also the site of a farmstead with a livestock feedyard many years earlier. This was substantiated when we examined the aerial photograph used in the Soil Survey of Buffalo County, Nebraska (SCS, 1974). Most of the very high soil test Bray-1 P values were located in this area of the field, probably due to the presence of the feedyard and the application of livestock manure from that feedyard in the near vicinity.

Dividing the field into the East and West halves using this knowledge and analyzing the data separately improved correlations (Table 2) and points out the importance of using and understanding past management effects. Our correlations of visual data with soil properties demonstrated that a composite aerial image of bare soil provided information that could be used to direct sampling efforts. They also demonstrated how several other factors can affect these relationships and how important it is to use all the information available when selecting sampling criteria for a particular field. Accumulation of this information year after year can result in a series of layers of data that can be used to best guide future sampling strategies to obtain the most accurate data from the field.

Note

1. Mention of commercial products and organizations in this publication is solely to provide specific information. It does not constitute endorsement by the USDA over other products and organizations not mentioned.

References

R. B. Ferguson, C. A. Gotway, G. W. Hergert, and T. A. Peterson, "Soil sampling for site-specific nitrogen management," in *Proceedings of the Third International Conference on Precision Agriculture*, edited by P. C. Robert, R. H. Rust, and W. E. Larson (ASA, CSSA, and SSSA, Madison, WI, 1996), p. 13–22.

Missouri Agricultural Experiment Station SB 1001, Recommended soil test procedures for the North Central Region, North Central Regional Research Publication No. 221 (revised), 1998.

S. Pocknee, B. C. Boydell, H. M. Green, D. J. Waters, and C. K. Kvien, "Directed soil sampling," in *Proceedings of the Third International Conference on Precision Agriculture*, edited by P. C. Robert, R. H. Rust, and W. E. Larson (ASA, CSSA, and SSSA, Madison, WI, 1996), p. 159–168.

SAS Institute, SAS/STAT User's Guide (4th ed.) (SAS Institute, Inc., Cary, NC, 1992).

G. W. Snedecor and W. G. Cochran, Statistical Methods (6th ed.) (The Iowa State University Press, Ames, Iowa, 1967).

Soil Survey Staff, Soil Survey of Buffalo County, Nebraska, USDA-SCS (U.S. Gov. Print. Office, Washington, D.C., 1974).

G. E. Varvel, F. N. Anderson, and G. A. Peterson, Agron. J. **73**, p. 516–520 (1981).

C. H. Wilcox, B. E. Frazier, and S. T. Ball, Photogrammetric Engineering and Remote Sensing **60**(6), p. 777–781 (1994).